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Evaluation of Radiological Exposure from Plowshare Applications 1967–1975

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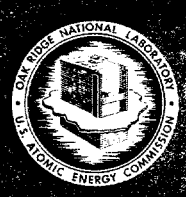

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EVALUATION OF RADIOLOGICAL EXPOSURE FROM PLOWSHARE APPLICATIONS 1967-1975

Compiled by

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ENVIRONMENTAL SCIENCES DIVISION

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ABSTRACT

A review of the highlights and accomplishments of the nine-year program, FY 1967-75, at ORNL on the evaluation of the radiological exposure from Plowshare applications is presented. Conclusions based on the studies summarized here are given. Chronological lists of presentations, reports and open literature publications on the various investigations of the program are appended to the report.

INTRODUCTION

The program in the Environmental Sciences Division of the Oak Ridge National Laboratory (ORNL) to evaluate radiological exposure resulting from Plowshare applications was terminated at the end of FY 1975. It seems appropriate, therefore, to review the accomplishments of this program which first received funding in FY 1967 from the Division of Peaceful Nuclear Explosives (DPNE), later part of the Division of Applied Technology of the AEC prior to formation of ERDA. This report updates and expands an unpublished report prepared in November 1972. Several events occurring between 1959 and 1966 actually set the stage for this contract. The first event took place in 1959 when L. C. Emerson, an ORNL health physicist, published an article (Nuclear Safety, 1, December 1959, pp. 49-52) discussing the relative importance of radionuclides produced by Plowshare detonations. Over the next several years several ORNL health physicists, notably E. G. Struxness,

continued to be interested in some of the unique radiological problems associated with Plowshare applications. Struxness attended Plowshare technical meetings and became acquainted with J. S. Kelly, Director of DPNE. The major trust of the Commission's Plowshare program at this time was directed toward developing cratering technology, and the discussions between Struxness and Plowshare representatives dwelled on the need for transient exposure guides for this situation.

Initial Plowshare activities in the Health Physics Division at ORNL were directed to the development and application of radiation safety guides for transient exposures and to the radiological safety assessment of excavation events, (e.g. Interoceanic Canal Studies). As the DPNE research and development shifted to gas stimulation, ORNL research likewise shifted to the radiological aspects of domestic uses of nuclearly stimulated natural gas. Dose estimations performed at ORNL for Plowshare gas users began with the Gasbuggy project in 1968 and continued with the Rulison project. Techniques were developed with general applicability to this type of dose evaluation. Because of the inadequate quantity of gas produced by the Rio Blanco event, no radiological evaluations related to this project were conducted at ORNL. A brief investigation of possible doses from use of tritiated gasoline in a metropolitan area was conducted in connection with a proposal by Lawrence Livermore Laboratory (LLL) to use nuclear explosives to expedite recovery of oil from oil shale.

In May 1972 administration of this program was transferred from the Health Physics Division to the Environmental Sciences Division and, as a result, the project enjoyed the close support of one of the nation's largest groups of environmental scientists. A summary of budget and manpower levels from FY 1967 through FY 1975 is shown in Table 1.

The basic recommendations of the International Commission on Radiological Protection (ICRP) set forth in its official publications constituted the framework around which the ORNL program was structured All evaluations of radiological exposure assessed in this activity were designed to consider all important radionuclides, exposure pathways, and exposed population groups, thus emphasizing a realistic appraisal of radiological dose. Site specific data were used whenever possible, and in the absence of such information the option was a realistically conservative estimate of the missing data. No formal program responsibilities for the validity of source term data were assigned to ORNL; however, at least a cursory evaluation was made of source term data supplied for dose estimations.

PROGRAM ACCOMPLISHMENTS, FY 1967 THROUGH FY 1975

This program has resulted in publication of a significant number of Laboratory reports and open literature publications in addition to presentation of numerous papers of scientific meetings. Pertinent oral presentations and publications are listed in Appendices I and II, respectively. Highlights of the project are presented in the following discussion.

Table 1

Budget Summary FY-1967 through FY-1975

Fiscal Year	Budget ($ x 10^3)
1967	21
1968	55
1969	88
1970	161
1971	265
1972	203
1973	200
1974	160
1975	126
Total	1,279

Cumulative Exposure Index (CUEX)

Funding at less than one man-year of effort during the first year of the project resulted in publication of an intercomparison of radiation guides recommended by recognized authorities, including suggestions in regard to the ones which might be applicable to nuclear excavation projects. The report covered recommendations of the ICRP, the International Atomic Energy Agency (IAEA), the National Commission on Radiological Protection (NCRP), the Federal Radiation Council (FRC), and the British Medical Research Council (MRC) and pointed out that, although the recommendations of all of the recognized authorities were generally consistent with one another, there were no guides that apply specifically to the transient exposure situations expected to result from Plowshare excavation-type projects. This significant conclusion early in the ORNL program provided justification for pursuing the development of a radiological transient exposure guide for excavation applications. Although the theoretical basis of an exposure guide called the CUmulative EXposure IndeX (CUEX) was worked out and published in FY 1970, limited progress was made toward completing the formulation and implementing the environmental models implicit in CUEX until this activity was split from the Plowshare program and supported as a separate program by the Division of Biomedical and Environmental Research (DBER) of the AEC. A CUEX is a time-integrated radionuclide concentration (e.g., μCi-hr/cm^3) for which the estimated total dose potential to man via all exposure pathways is equal to a preselected dose limit. The assessment is achieved by estimating the

total radiation dose to man via all radionuclides and exposure pathways, and by comparing the dose estimate with the appropriate dose limit. The DBER acknowledged CUEX as a significant new exposure guide providing distinct advantages over the use of MPC's and other methods of assessing radiation exposure situations associated with environmental releases of radioactivity.

Interoceanic Canal Feasibility Study

Concommitant with initiation of formal support from Plowshare in FY 1967, the Health Physics Division received a subcontract from Battelle Columbus Laboratories to do the official dose estimates for the feasibility study of constructing a sea-level canal with nuclear devices in Panama or Columbia. Battelle was a prime contractor to the AEC to direct the overall bioenvirionmental feasibility study. This study provided a good opportunity for further testing and development of computer codes and methods of assessment initiated under direct Plowshare support. The final report (ORNL-4576) summarizing ORNL's dose estimates for the feasibility study was issued in 1970, and part of the information was incorporated into AEC's report to the Interoceanic Canal Study Commission which, in turn, reported to the President of the United States.

Computer Codes for Estimation of Internal and External Doses

The INREM and EXREM computer codes (K-1752, 1968) for estimation of internal and external doses, respectively, were made operational in FY 1968 and, with some improvements, are still in routine use. These codes compute internal age-dependent dose from ingestion and inhalation, and external doses from immersion in a radioactive cloud,

immersion in contaminated water, and exposure above a contaminated landscape. Besides being used for Plowshare over the past several years, dose estimates computed with INREM and EXREM appear in radiological sections of environmental impact statements prepared at ORNL for a variety of nuclear programs and facilities. These dose estimates are computed for both man and native biota. The INREM Code is recognized for its unique capability of calculating dose as a function of the age of the individual; that is, the five major age-dependent parameters in the internal dose model change as the person ages during the integration of dose commitment over time.

Feasibility Study of Worldwide Excavation Projects

The ORNL Plowshare Dose Group has cooperated closely with LLL on several projects of mutual interest, especially a study of the theoretical radiological feasibility of 13 worldwide nuclear excavation projects. This study was completed in September 1970; ORNL provided an analysis of the food chain transport, estimates of potential somatic and genetically significant dose to man, and interpretation of the dose estimates in relation to present dose limits of the ICRP. The results of this study were presented orally and in report form (by LLL) to the Commissioners of the AEC.

Environmental Systems Analysis

Funding for this Plowshare activity in 1968 resulted in the first open literature publications (BioScience, 1969) demonstrating the great potential of applying systems analysis techniques to

simulate and predict environmental food chain transfers of radioactivity. The example cited in the publication pertained to the proposed excavation of a sea-level canal with nuclear explosives. Many researchers in the past few years have followed the lead of the ORNL program by employing systems analysis to solve environmental transport problems. The ORNL thesis is that systems analysis provides a means for realistic simulation of radionuclide movement in environmental pathways and thus may result in the most realistic estimates of radiation dose. Several environmental systems analysis models developed originally at ORNL for Plowshare are used to assess radioactivity releases from nuclear facilities.

Methodology of Radiological Assessment for Plowshare Gas

The objectives of the research in the area of gas stimulation were to provide sufficient background information (1) to evaluate the radiological feasibility of using nuclearly stimulated gas in households and commercial plants, including electric generating stations; (2) to provide sound information which might be used by the government in establishing regulations and in issuing licenses for the sale and consumption of nuclearly stimulated gas; and (3) to suggest ways of reducing estimated radiation exposures to "as low as practicable" levels.

The ORNL approach to project related dose estimations is outlined below, with some explanatory comments. (1) Determing the wellhead concentration of radionuclides in the natural gas,

averaged over the period of interest, usually 1 year. Samples of cavity gas were removed during the well testing programs and were analyzed both for chemical and radiochemical composition. Some of these analyses were performed at ORNL, but this was not a prime ORNL responsibility. (2) Calculate dilution of radionuclides in a real gas distribution system to provide estimates of concentrations at points of use. In order to relate the results of theoretical dose studies as closely as possible to real life, close liaison was maintained with gas transmission companies that were potential distributors of gas from nuclearly stimulated wells. They provided data on gas flow rates in their systems and on gas usage. (3) Calculate atmospheric dilution of gas combustion products. Data developed in Step 2 were used to calculate average potential concentrations of radionuclides in the air that gas users and other members of the exposed public might breathe. A variety of atmospheric dilution situations were considered. (4) Calculate whole body doses. Most dose estimations were for tritiated water vapor (HTO) in gas combution products, and the exposure pathway considered in greatest detail was inhalation and skin absorption of HTO. Whole body doses from ^{85}Kr in gas were estimated to be approximately 2% of the dose from HTO.

Gasbuggy

The Gasbuggy Project, a joint endeavor of the AEC and EL Paso Natural Gas Company (EPNG), performed the first test of the use of an underground nuclear explosion to increase gas production. The

ORNL dose estimations related to this project represented the first detailed study of the radiological impact of use of natural gas containing man-made radionuclides. The approach outlined above was worked out in cooperation with EPNG which supplied the data on gas system dilution and other needed information. The study was divided into two parts: Phase I covered doses potentially received within the San Juan Basin, the gas-production area in which the Gasbuggy well is located (Phase I report, 1971); and Phase II covered hypothetical uses of Gasbuggy gas outside the San Juan Basin, principally in the Los Angeles and San Francisco metropolitan areas (Phase II report, 1972). These studies clearly demonstrated that tritium is the radionuclide of principal concern in nuclearly stimulated natural gas, that home consumption of gas in unvented heaters or appliances is the critical exposure pathway, and that the average annual whole body dose will be less than 1 millirem if the tritium concentration in the gas is limited to 1 pCi/cm^3 at the point of use. A later examination of nonfuel uses of gas having this tritium concentration (ORNL-TM-4730, 1974) indicated that human consumption of tritiated gas by-products is not likely to result in larger whole body doses than those received by inhalation and skin absorption of HTO in gas combustion products. Similarly, in a study of radiation doses from food cooked with gas containing the same concentration of tritium, the annual whole-body dose to each individual ingesting the food was estimated to be 0.02 millirem (ORNL-TM-4735, 1974).

Also included in these studies was an experiment in which gas from the Gasbuggy well was diluted with uncontaminated natural gas and processed in a small plant in West Texas. The results of this test performed with the help of EPNG showed that tritium in the gas was distributed among plant products according to the predicted pattern and that plant workers are unlikely to receive excessive radiation doses from this type of operation (ORNL-4775, 1972).

Rulison

Dose estimations related to the Rulison project, which resulted in the second test of the nuclear gas stimulation concept, applied the techniques developed in the Gasbuggy studies to gas uses on a scale that may be approximated in the first licensed use of gas from a nuclearly stimulated well. Meteorological conditions encountered in western Colorado communities potentially receiving Rulison gas were quite different from those encountered in California. The principal source of potential exposure was identified as use of gas in unvented kitchen ranges, confirming the earlier conclusion that home gas use constitutes the critical exposure pathway (Nuclear Technology 20, 35, 1973).

Also considered in the Rulison studies was the use of gas from a multiwell field to generate electricity in a plant located in the metropolitan Denver area. Gas in this case was assumed to contain 10 pCi ^{3}H per cm^{3}. Maximum potential individual doses to people living in the vicinity of the plant were calculated with the stack

dose computer code mentioned below and were estimated to be two orders of magnitude smaller than doses received by people using the same gas for cooking in homes. In order to calculate total population doses from this point source (high stack), computer codes were developed to deal with an unusual meteorological condition that prevails in this area. Wind reversal that occurs almost daily results in the return of diffuse plumes to the populated area, but the total dose to 1.4 million people was estimated to be less than 5 man-rems per year (Nuclear Technology 24, 238, 1974).

Radon in Natural Gas

Because of the expectation that man-made radionuclides would be introduced into natural gas by use of nuclear explosives, it was considered necessary to evaluate radiation doses that people receive from the naturally occurring radon in gas. A literature survey in FY 1971 showed that data were available on the radon content of natural gas from many wells but almost none was found on the radon concentration in gas at points of use or on doses that people receive from exposure to this natural radionuclide in gas. A cooperative effort with several large gas transmission companies in supplying gas samples at monthly intervals over a period of approximately one year and of several institutions in measuring the radon concentrations in samples yielded the needed data on radon concentrations in natural gas used in several metropolitan areas. Computer codes were formulated to calculate the radiation doses to the bronchial epithelium of people living in a home with an unvented kitchen range. The maximum estimated doses were considered to be small when compared to variations

in dose from radon and its daughters in ambient air. We concluded that other factors such as home construction material and ventilation rate are more important than the radon concentration in natural gas in determining the level of airborne natural radioactivity in homes.

Computer Codes for Multiple-Well Developments

Two computer codes written in FY 1972 may aid in planning the schedule for opening nuclearly stimulated wells in a multiple-well development. WELLFIELD computes daily tritium concentrations for 20 years in natural gas flowing from a field with a large number of wells which are opened to a common pipeline at stated times. WELLFIELD MAX determines the temporal spacing of wells that will keep the average tritium concentration in the gas below a desired maximum value. These codes were used only for theoretical situations (ORNL-TM-3755, 1972).

Computer Codes for Calculation of Individual and Population Doses

STACKDOSE estimates the maximum annual tritium dose that any person living near a power plant burning nuclearly stimulated natural gas might receive from exposure to the plumes. STACKDOSE MAX estimates the highest average tritium concentration that may be permitted in the natural gas used in a power plant in order that no person living near the plant would receive more than a specified annual tritium dose (ORNL-TM-3755, 1972). STACKMANREM estimates the man-rem dose by considering the population distribution and

the calculated doses to individuals in the population. The latter code was used to evaluate the population dose from hypothetical use of nuclearly stimulated gas in the Cherokee Electric Generating Plant in Denver, Colorado (ORNL-TM-4026, 1973 and Nuclear Technology 24, 238, 1974). The above codes deal only with point sources. AIRDOT estimates doses to individuals and populations from sources dispersed over an area, a situation that would result from use of nuclearly stimulated natural gas in homes and commercial establishments in a metropolitan area. This code is presently undocumented.

Estimation of Doses from Use of Tritiated Gasoline

A brief study was made of the hypothetical radiation dose that could result from use of tritiated gasoline, such as might occur if nuclear explosives were used to promote the recovery of oil from oil shale. We assumed that all gasoline fueling automobiles in the Denver Metropolitan area contained 5 μCi of tritium per gallon and, with the help of the AIRDOT Code, we estimated that the maximum potential whole-body dose to an individual in the area could be 0.006 millirem/year while the total population dose could be 2.4 man-rem/year.

ICRP

Close contact has been maintained with the ICRP, and several of the project staff have been involved as members of Committee IV and its special task groups. This work reached an important milestone

in June 1972 with submission to the ICRP of a draft report prepared at ORNL, entitled: "Radiation Protection Assessments Related to Planned and Unplanned Releases of Radioactive Materials into the Environment." The report essentially summarizes the philosophy, methodologies, and some of the concentration factors and systems analysis methods developed under this activity.

US-USSR Bilateral Talks and IAEA Panels on Peaceful Nuclear Explosions

ORNL personnel participated in the second, third and fourth US-USSR bilateral talks and IAEA panels on Peaceful Nuclear Explosions and represented the United States in areas dealing with radiation standards, guides, and their interpretations. The ORNL representatives concluded that the Russians readily accept ICRP recommendations and that the best avenue of agreement on radiation guides applicable to International Plowshare activities may be through the IAEA.

CONCLUSIONS

Potential doses to persons exposed to combustion products of natural gas containing man-made radionuclides, the part of the program that was emphasized at ORNL for more than half of its existence, were estimated to be a small fraction of the dose that people receive from naturally occurring radionuclides and from medical exposures. Also, doses from the natural radionuclides in the same gas (radon and its

daughters) were estimated to be small when compared to doses from the same radionuclides in the atmosphere.

Not all the objectives of the program were achieved because of its premature termination but a great deal was accomplished in developing models and computer codes that are finding application in other areas, both nuclear and non-nuclear.

APPENDIX I

List of Oral Presentations

1966

S. V. Kaye

The Specific Activity Concept and Internal Dosimetry. Bioenvironmental Subcontractors Meeting for Sea-Level Canal Studies, November 15-17, 1966, Columbus, Ohio.

Environmental Pathways and Internal Dosimetry, Bioenvironmental Subcontractors meeting for Sea-Level Canal Studies, November 15-17, 1966, Columbus, Ohio.

1967

S. V. Kaye and S. J. Ball

A Coupled Compartment Model for Radionuclide Transfer in a Tropical Environment, Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan.

S. V. Kaye

Status of the ORNL Dose Estimation Program Related to Excavation of a Sea-Level Canal with Nuclear Explosives, Subcontractors Working Meeting, Battelle Memorial Institute, November 14, 1967, Columbus, Ohio.

1968

S. V. Kaye, P. S. Rohwer, K. E. Cowser, and W. D. Turner

Estimating Radiation Doses to Populations for Projects Involving Reactor Siting and Peaceful Nuclear Explosives, Annual Meeting of the Health Physics Society, June 16-20, 1968, Denver, Colorado.

S. V. Kaye, P. S. Rohwer, K. E. Cowser, and W. S. Snyder

Predicting Radiation Dose Equivalents for Populations. I. Dose Models and Methods of Application, AIBS Symposium, "Sea Level Canal, Bioenvironmental Studies," September 3-6, 1968, Columbus, Ohio.

APPENDIX I (cont'd)

1968

P. S. Rohwer and S. V. Kaye

Predicting Radiation Dose Equivalents for Populations. II. Results Obtained with the Dose Models, AIBS Symposium, "Sea Level Canal, Bioenvironmental Studies," September 3-6, 1968, Columbus, Ohio.

1969

K. E. Cowser, W. S. Snyder, and E. G. Struxness

Application of ICRP Recommendations Relevant to Internal Dose, Symposium on Public Health Aspects of Peaceful Uses of Nuclear Explosives, April 7-11, 1969, Las Vegas, Nevada.

S. V. Kaye and P. S. Rohwer

Methods of Estimating Population Exposures from Plowshare Applications, Symposium on Public Health Aspects of Peaceful Uses of Nuclear Explosives, April 7-11, 1969, Las Vegas, Nevada.

1970

D. G. Jacobs, E. G. Struxness, and C. R. Bowman

A Preliminary Assessment of the Radiological Implications of Commercial Utilization of Natural Gas from a Nuclearly Stimulated Well, Fourth Plowshare Symposium, January 14-16, 1970, Las Vegas, Nevada.

E. G. Struxness and P. S. Rohwer

An Approach to the Development of Guidelines for Plowshare, presented at 2nd Session of U.S.-U.S.S.R. Exchange Talks, Moscow, February 10-18, 1970.

D. G. Jacobs, E. G. Struxness, M. J. Kelly, and C. R. Bowman

Consideration of the Radiological Impact from the Hypothetical Use of Contaminated Natural Gas from Nuclearly Stimulated Reservoirs, Second International Congress of the International Radiation Protection Association, May 3-8, 1970, Brighton, England.

C. J. Barton, D. G. Jacobs, M. J. Kelly, and E. G. Struxness

Radiological Considerations in the Use of Natural Gas from Nuclearly Stimulated Wells, Atomic Industrial Forum 1970 Annual Conference, November 17, 1970, Washington, D. C.

APPENDIX I (cont'd)

1971

D. G. Jacobs and E. G. Struxness

Radiological Safety Considerations in the Distribution of Natural Gas Containing Radionuclides, Second International Atomic Energy Agency Panel on Plowshare, January 17-22, 1971, Vienna, Austria.

P. S. Rohwer and E. G. Struxness

Development of Radiation Safety Indices for Environmental Releases of Radioactivity, 16th Annual Meeting of Health Physics Society, July 11-15, 1971, New York.

R. S. Booth and S. V. Kaye

A Systems Analysis Model of Radioactivity Transfer to Man from Deposition in a Terrestrial Environment, Annual Meeting of Health Physics Society, July 13, 1971, New York.

E. G. Struxness

External and Internal Doses to Man from Natural Background Radiation and Deposited Artificial Radioactivity, 3rd Session of U.S.-U.S.S.R. Technical Talks on Plowshare, Washington, D. C., July 12-23, 1971.

P. S. Rohwer, R. S. Booth, S. V. Kaye, M. J. Kelly, and E. G. Struxness

Evaluation of Potential Exposure to Environmental Radioactivity, 3rd Session of U.S.-U.S.S.R. Technical Talks on Plowshare, Washington, D. C., July 12-23, 1971.

M. J. Kelly

Confirmation that Concentrations of Released Radionuclides Exposing Man Do Not Exceed Acceptable Levels, 3rd Session of U.S.-U.S.S.R. Technical Talks on Plowshare, Washington, D. C., July 12-23, 1971.

M. J. Kelly, R. S. Booth, S. V. Kaye, and P. S. Rohwer

Modeling the Environmental Behavior of Radionuclides and Estimating Doses to Man, 3rd Session of U.S.-U.S.S.R. Technical Talks on Plowshare, Washington, D. C., July 12-23, 1971.

APPENDIX I (cont'd)

1971

M. J. Kelly, C. J. Barton, A. S. Meyer, E. W. Chew, and C. R. Bowman

Experimental Results from Processing Gasbuggy Gas in a Natural Gas Processing Plant, Tritium Symposium, August 30-September 2, 1971, Las Vegas, Nevada.

S. V. Kaye, R. S. Booth, P. S. Rohwer, and E. G. Struxness

A Cumulative Exposure Index (CUEX) for Assessing Environmental Releases of Radioactivity, International Symposium on Radioecology Applied to the Protection of Man and His Environment, September 7-10, 1971, Rome, Italy.

1972

C. J. Barton, R. E. Moore, and S. R. Hanna

Dose Estimates for Hypothetical Uses of Rulison Gas, Health Physics Society Meeting, June 1972, Las Vegas, Nevada.

M. J. Kelly, P. S. Rohwer, C. J. Barton, and E. G. Struxness

Relative Risks from Radionuclides Found in Nuclearly Stimulated Natural Gas, 3rd IAEA PNE Panel, November 26-30, 1972, Vienna, Austria.

1973

C. J. Barton, R. E. Moore, and P. S. Rohwer

Contribution of Radon in Natural Gas to the Dose from Airborne Radon Daughters in Homes, presented at the Noble Gases Symposium, Las Vegas, Nevada, September 24-28, 1973.

P. S. Rohwer, C. J. Barton, R. E. Moore, and S. V. Kaye

An Evaluation of Nuclear Gas Stimulation in Terms of Potential Radiation Exposure to the Public, presented at the Third International Radiological Protection Association Meeting, Washington, D. C., September 9-14, 1973.

P. S. Rohwer and M. J. Kelly

Relative Radiological Importance of Tritium and Krypton-85 in Nuclearly Stimulated Natural Gas, presented at Eighteenth Annual Meeting of the Health Physics Society, Miami Beach, Florida, June 17-21, 1973.

APPENDIX I (cont'd)

1974

P. S. Rohwer, C. J. Barton, and R. E. Moore

Large Scale Nuclear Gas Stimulation: Population Doses Estimated in the Environmental Assessment of Carbon-14 Releases, presented at the Eighth Midyear Topical Symposium of the Health Physics Society, Population Exposures, Knoxville, Tennessee, Oct. 21-24, 1974.

C. J. Barton, R. E. Moore, and P. S. Rohwer

Philosophy and Methodology of Assessment of Doses to Populations from Combustion Products of Plowshare Natural Gas, presented at the Eighth Midyear Topical Symposium of the Health Physics Society, Population Exposures, Knoxville, Tennessee, Oct. 21-24, 1974.

1975

C. J. Barton, R. E. Moore, P. S. Rohwer, and S. V. Kaye

Calculational Techniques for Estimating Population Doses from Radioactivity in Natural Gas from Nuclearly Stimulated Wells, presented at the Fourth IAEA Panel on Peaceful Nuclear Explosives, Vienna, Austria, January 1975.

P. S. Rohwer, S. V. Kaye, and E. G. Struxness

Methodology for Assessing Environmental Releases of Radioactivity in the Context of ICRP Recommendations, presented at the Fourth IAEA Panel on Peaceful Nuclear Explosives, Vienna, Austria, January 1975.

APPENDIX II

Publications List

1967

K. E. Cowser, S. V. Kaye, P. S. Rohwer, W. S. Snyder, and E. G. Struxness

Dose-Estimation Studies Related to Proposed Construction of an Atlantic-Pacific Interoceanic Canal with Nuclear Explosives: Phase 1, ORNL-4101 (March 1967).

E. G. Struxness, W. S. Snyder, and K. E. Cowser

Radiation Standards for Transient Exposures, Progress Report for July 1, 1966 to January 1, 1967, ORNL-TM-1827 (April 1967).

P. S. Rohwer and E. G. Struxness

Evaluation of the Biological Effects of Radiation, ORNL-CF-67-9-60 (September 1967).

1968

P. S. Rohwer and S. V. Kaye

Age-Dependent Models for Estimating Internal Dose in Feasibility Evaluations of Plowshare Events, ORNL-TM-2229 (June 1968).

S. V. Kaye and P. S. Rohwer

Estimating External Dose in Feasibility Evaluations of Plowshare Events, ORNL-TM-2249 (July 1968).

W. D. Turner, S. V. Kaye, and P. S. Rohwer

EXREM and INREM Computer Codes for Estimating Radiation Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives, K-1752 (July 1968).

APPENDIX II (cont'd)

1969

D. G. Jacobs, E. G. Struxness, and M. J. Kelly

First Quarterly Progress Report on the Theoretical Safety Evaluation of Consumer Products from Project Gasbuggy, ORNL-TM-2427 (February 1969).

M. J. Kelly, P. S. Rohwer, D. G. Jacobs, and C. R. Bowman

Second Quarterly Progress Report on the Theoretical Evaluation of Consumer Products from Project Gasbuggy, ORNL-TM-2513 (March 1969).

S. V. Kaye, P. S. Rohwer, K. E. Cowser, and W. S. Snyder

"Predicting Radiation Dose Equivalents for Populations: I. Dose Models and Methods of Application," BioScience 19, 238-41 (1969).

P. S. Rohwer and S. V. Kaye

"Predicting Radiation Dose Equivalents for Populations: II. Results Obtained with the Dose Models," BioScience 19, 326-30 (1969).

K. E. Cowser, W. S. Snyder, and E. G. Struxness

"Application of ICRP Recommendations Relevant to Internal Dose," Proceedings of the Symposium on Public Health Aspects of Peaceful Uses of Nuclear Explosives, April 7-11, 1969, Las Vegas, Nevada, SWRHL-82, pp. 550-84.

D. G. Jacobs, P. S. Rohwer, and K. E. Cowser

Third Quarterly Progress Report on the Theoretical Evaluation of Consumer Products from Project Gasbuggy, ORNL-TM-2657 (July 1969).

D. G. Jacobs and M. J. Kelly

Fourth Quarterly Progress Report on the Theoretical Evaluation of Consumer Products from Project Gasbuggy, ORNL-TM-2721 (October 1969).

1970

D. G. Jacobs, E. G. Struxness, and C. R. Bowman

"A Preliminary Assessment of the Radiological Implications of Commercial Utilization of Natural Gas from a Nuclearly Stimulated Well," p. 831 in Proceedings of the ANS Topical Meeting, Engineering with Nuclear Explosives, Las Vegas, Nevada, January 1970, CONF-700101, vol. I (1970).

APPENDIX II (cont'd)

D. G. Jacobs and M. J. Kelly

Fifth Quarterly Progress Report on the Theoretical Evaluation of Consumer Products from Nuclearly Stimulated Gas Wells, ORNL-TM-2862 (February 1970).

P. S. Rohwer and E. G. Struxness

Quarterly Progress Report on Radiological Safety of Peaceful Uses of Nuclear Explosives: Development of Transient-Exposure Guides, ORNL-TM-2810 (May 1970).

S. V. Kaye and P. S. Rohwer

Dose Estimation Studies Related to Proposed Construction of an Atlantic-Pacific Interoceanic Canal with Nuclear Explosives: Phase III, ORNL-4579 (December 1970).

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